

1514 Xanthisma
McAllen, Tx 78501
Jan. 14, 1975

Dr. Wallace P. Murdoch, Editor
Bulletin of the Entomological
Society of America
ESA, Box AJ
4603 Calvert Road
College Park, MD 20740

Dear Wally,

Enclosed is the manuscript, Screwworm Research and Eradication, which I presented as the Founders' Memorial Lecture at Minneapolis. I hope that you will find it suitable for publication in the Bulletin.

Again I wish to thank the Society for the privilege and honor of giving that lecture.

Sincerely,

Bush

R. C. Bushland
ARS Entomologist, Retired

cc:

→ E. A. Taylor
E. F. Knipling

SCREWWORM RESEARCH AND ERADICATION^{1/}

by

R. C. Bushland

USDA, ARS (Retired)

At a former air base converted to an insectary, fly sterilization and dispersal center, near Mission, Texas, the Animal and Plant Health Inspection Service (APHIS) of the USDA is producing and distributing approximately 200 million sterile screwworm flies, Cochliomyia hominivorax (Coquerel), per week. Meanwhile, there is under construction another screwworm plant near Tuxtla Gutierrez, Chiapas, Mexico. This facility belongs to the Mexico-United States Commission for the Eradication of Screwworms. The new insectary is planned to begin producing 300 million flies weekly about a year from now.

The combined production in Texas and Mexico of one-half billion sterile flies each week is expected to be sufficient to overflow the wild fly population leading to eradication of screwworms from the area north of the Isthmus of Tehuantepec.

This huge enterprise was not anticipated in 1938 when E. F. Knipling first proposed sterilizing screwworm flies. Today I'll talk about how the program grew and about some of the associated unsolved research problems.

There is not time to cite the many contributions^{2/} of my associates in the USDA but I must acknowledge the work of two who died this year. E. C. Cushing corrected taxonomic confusion about the species and established that the screwworm larva is an obligatory parasite. C. N. Husman built entomology laboratories, engineered the sterile fly factories, and invented much of the equipment for mass rearing and distribution.

Screwworms live throughout the year in the tropic and subtropic regions of the Americas. In the summer months they extend their range through seasonal migration into temperate zones of North and South America. Before 1933 in the United States screwworms would spread each year from overwintering areas near the Mexican border and from Mexico about as far north as Kansas City in the Midwest and to Sacramento in the Far West. The main summer infestation was in the Midwest and did not extend to the Southeast. In 1933 screwworms appeared in Georgia, apparently having been introduced by transport of infested cattle from the Southwest. Flies spread into Florida and overwintered in the subtropical peninsula. This established a new southeastern population that spread hundreds of miles north each summer.

The flies oviposit on wounds of warm-blooded animals, chiefly neglected livestock, and the larvae feed in the living flesh. In the laboratory we can rear screwworms on heated nutritional media. There was an attempt from 1935 to 1937 to

eliminate screwworms from the Southeast by animal husbandry and chemical control methods. The population was greatly reduced, but not eradicated.

Knipling proposed in conversations that if only some way could be found to sterilize flies, it should be possible to outnumber the small overwintering population in Florida. We did not start experiments until the Kerrville laboratory was established in 1947. Our first efforts were at chemical sterilization as a sideline to insecticide screening.

We did not enjoy success until in 1950 when we finally became aware of what insect geneticists had long known about radiation-induced dominant lethal mutations.

We had little trouble working out doses of radiation that sterilized flies without greatly shortening their life span or unduly handicapping them in competition for mates in cages.

As soon as we knew how to sterilize flies with X-rays we began field tests on Sanibel Island, Florida using screwworms shipped from Kerrville. Population estimates were made by releasing P-32 labelled fertile adults and comparing numbers of radioactive egg masses from released flies with non-radioactive masses laid by wild flies on wounded goats. We also compared relative numbers of labelled to unlabelled flies caught in liver-baited traps. Those studies confirmed the hope that 100 pairs of released flies per square mile should greatly outnumber

the wild population. Releasing X-ray sterilized flies, at the rate of 100 males (plus 100 sterile females) per square mile per week, caused a preponderance of sterile matings in the wild population as indicated by the hatch of egg masses laid on trap wounds by wild flies.

The opportunity for an eradication experiment on an isolated island came in 1954 with a request for assistance from Dutch officials on the Island of Curacao. This 170 square-mile island, about 50 miles off the coast of Venezuela was heavily infested with screwworms. A release rate of 200 flies per square mile per week which seemed so promising in our Florida tests caused only about 15% sterile matings but when the rate was increased to 800 flies, sterility of egg masses averaged about 70%. This rate of sterility caused a marked decline in the wild population and the percentage of sterile egg masses increased as the number of egg masses diminished. Eradication was accomplished within 6 months.

In the summer of 1957 we conducted a pilot test, rearing 2 million flies per week and releasing them over a 2,000 square-mile area near Orlando. Sterility of egg masses collected in the center of the test area reached 70%, the magic number that started the downfall of screwworms on Curacao; so the research project was concluded. Our Florida staff were transferred from the Entomology Research Division to work with veterinarians of the Animal Disease Eradication Division in the Southeastern Eradication Program which was a joint effort of the USDA and regulatory agencies of the southeastern states.

The Agricultural Research Service has continued research in support of screwworm eradication programs but the execution of the programs is an APHIS effort with research assistance and advice from ARS.

The southeastern program succeeded more rapidly than we had expected. Unusually severe cold in December 1957 and January 1958 killed screwworms from the area north of Orlando. To take advantage of the unusual weather, the research pilot plant at Orlando was put into a crash program of fly production while the main rearing plant was under construction at Sebring. Sterile fly production started at 1 million per week in January and by July, when the Sebring plant opened, was up to 14 million weekly. Those numbers were insufficient to treat the southern half of Florida, where flies survived the cold, but they were used in an experimental barrier zone spread over the northern half of the state. The sterile flies, plus inspection and insecticide treatment of livestock being shipped north of the overwintering areas, confined the infestation and prevented the usual spring migration into the southeastern states.

When the main fly factory opened at Sebring in July 1958, producing 60 million sterile flies weekly, the whole peninsula was flooded with sterile flies at the rate of 1,000 per square mile per week. Screwworms almost disappeared within 6 months and the last case was recorded in June 1959. The Sebring plant was closed in November.

The success of the barrier zone in northern Florida changed our thinking about the prospects for screwworm eradication in

the Southwest. Previously we had considered it impractical to cope with flies migrating across our 1800-mile border with Mexico. But the principal overwintering area in Texas was no larger than the usual overwintering zone in subtropical Florida. There was minor overwintering of flies in the warmest parts of New Mexico, Arizona and California but this western population did not migrate eastward because of arid and mountainous terrain. Therefore it seemed practical to try a three-step program. Part one was to overflow the winter survival area in Texas and adjacent Mexico to eliminate overwintering there. The next step was to put a 100-mile wide barrier zone of flies along the Rio Grande River. Step 3 was to extend the eradication area to the Pacific Ocean if the first two steps were successful.

This program was recognized as an experiment by the sponsoring agencies. Livestock interests in the Southwest raised 4.5 million dollars in free will donations to the Southwest Animal Health Research Foundation to match federal funds for the attempt. This huge experiment was considered a good businessman's gamble by the livestock producers who paid half the cost. The effort was budgeted at 5 million dollars per year and the industry was suffering an estimated 100 million dollars annual loss.

The program got started in February 1962. Aided by an unusually cold winter to limit overwintering, success was rapid. As in Florida, flies were produced at an expanded ARS facility at Kerrville until a 100 million fly capacity plant was completed at Mission, Texas. In 1962 control was estimated to be about 90% as compared with previous years. In 1963 it was 99% and by 1964 screwworms were officially considered eradicated from Texas and New Mexico. Arizona and California were then added to the eradication area and the whole U.S. was declared free of screwworms in 1966.

By declaring screwworms eradicated from the United States the Department of Agriculture assumed the fiscal responsibility for protecting the border states from Mexican flies. Some flies still invaded from Mexico. We had thought at the beginning of the program that a migrating fly would die of old age before crossing a 100 mile-wide barrier zone. We were proved wrong by trapping marked sterile flies as far as 180 miles from the release point. We now believe that some wild flies travel 300 miles.

By extending the barrier zone in critical areas to a width of 300 miles, making special releases of sterile flies in places where flies invade beyond the barrier zone and spraying cattle in such locations, APHIS has effectively protected most of the U.S.

Every year some screwworm cases occur in this country but most years there were no continuously infested areas. In the years 1968, 1972, 1973 and 1974 the program did not prevent continuous breeding of screwworms in some localities - particularly in South Texas. However, except for the 1972 outbreak, failures were localized. Even in 1972 the program was cost-effective, protecting the majority of livestock.

There has been much speculation concerning the causes of the recent screwworm outbreaks. Failures have been attributed to: (1) weather, (2) changed ranch practices, (3) not enough sterile flies, (4) inferior quality of sterile flies due to changes in mass rearing, (5) improper dispersal of sterile flies, (6) loss of competitiveness of sterile flies because of genetic deterioration of laboratory breeding stocks, and (7) genetic changes in the wild population.

(1) Weather has long been recognized to affect screwworm populations. A warm winter favors survival of this subtropical insect and in a wet summer screwworms increase much more than in that normally dry season in the Southwest. It is true that the weather was favorable in those bad years, but I can't blame all of our troubles on the weather. Sterile flies have controlled screwworms during weather favoring screwworm increase.

(2) Ranch practices have indeed changed. Much of the 100 million dollars annual toll from screwworms before the program was in the cost of preventive animal husbandry. During the screwworm-free years since 1963 the ranchers saved much of that 100 million by eliminating cowboys and horses that were employed chiefly in screwworm control. The ranchers have also neglected control of lone star ticks, Gulf Coast ticks and horn flies whose bites make livestock susceptible to screwworms. Now, when outbreaks occur, growers cannot immediately respond because, after 10 years, dipping vats have been abandoned, spray equipment has deteriorated, pens have fallen into disrepair, cow ponies have disappeared and there are no replacements for the skilled cowboys who once rode the pastures inspecting every animal at least once a week and doctoring those infested. Cows used to be bred to calve in the colder months but in the years without screwworms it became more profitable to have calves later when pastures are good. Now unprotected newborn calves are major hosts for screwworm increase. There are also more deer as wild hosts but a bigger problem is the vast number of neglected livestock.

(3) The third point of an insufficient number of sterile flies was compensated for as a result of the outbreak of 1968. Production was doubled to provide for releasing 200 million sterile flies weekly. During the next three years there was

good control and it seems that doubled production may have compensated for some of the factors already discussed. However, sterile flies at the rate 200 per square mile per week were effective in controlling established populations in our early Florida experiments so that number should be adequate in a barrier zone to prevent a population from becoming established. As present production provides for greater release rates, I think that enough flies are being produced for the barrier. Once screwworms infest a wide area, and build up to large populations, sterile flies alone are not enough to bring about control.

(4) The fourth possibility of poor quality flies has received very serious consideration by both APHIS and ARS people. It has been necessary to change the larval diet for mass rearing. Our early field tests were made with flies grown on ground horsemeat mixed with fresh citrated beef blood, water and preservative. In the Florida eradication program whale meat was substituted for horsemeat. In the Southwestern program ground nutria has been the principle fresh meat but, because of inadequate supplies of any meat, the diet now relied on is a mixture of dried milk, powdered egg, dried blood, water and preservative with cotton linters added to thicken the mixture and support the larvae. The only components not changed are the water and formaldehyde. There has been attention to

quality control as a routine matter on each and every day's production of sterile flies with special evaluations by both ARS and the Methods Development section of APHIS for every major change in the diet. These special tests involve not only measurements of size and vigor in the laboratory, but field observations, particularly release and trap-back studies to give reasonable assurance that fly quality is as good as possible within limits of budget and sources of supply. My general conclusions are that none of the mass-reared flies have been as large or as vigorous as the research insects reared in smaller numbers on the horsemeat diet. But I do believe that the flies reared on whale meat in Florida were not as good as the flies being reared today.

(5) The fifth suggestion that dispersal techniques are inferior to those used earlier in screwworm eradication has also been studied. In the Florida program and at the beginning of eradication in South Texas flies were released from single engine airplanes at low altitude over lanes spaced 2 miles apart each week and adjusted on alternate weeks so that every 2 weeks the area was covered in flight lanes one mile apart. The greater distances involved in the southwestern program and safety considerations for flying over mountainous terrain require twin engine aircraft flying at higher altitudes. Flies have been put out in larger boxes over lanes 10 miles apart to save on dispersal expense but, in general, distribution has been

in 5-mile flight lanes with special additional releases over major water courses where flies congregate in hot, dry weather and with so-called "hot-spot" releases over newly infested areas. Records on trap-back of marked sterile flies indicate that the 5-mile lanes are adequate.

(6) The sixth item, genetic deterioration of laboratory breeding stocks, has been a major worry in recent years. To begin with, we didn't know enough about insect genetics to be worried and we got along fine. The original screwworm colony was in the laboratory at Dallas when I came to work in 1935. I think that the colony was about a year old then, with the larvae being reared on wounded rabbits or calves. Starting in 1936 we raised the larvae on the artificial diet. The Dallas colony was moved to Menard in 1937 and in 1946 it was transferred to Kerrville. So far as I know, there was no introduction of wild genes in all that time. Starting in 1947 at Kerrville we collected wild egg masses each spring and sometimes in the fall. We reared the larvae on artificial diet and without much care put the resulting adults or flies of the next laboratory generation in with the old colony. I thought that we were introducing wild genes then - but now I doubt it. The old colony was adapted and the wild flies were not. I suspect that most wild genes were eliminated in succeeding generations. This colony furnished the flies for our first Sanibel Island experiments. A subcolony was sent

to Florida in 1951 and without further addition of wild flies was used for eradication of screwworms from Curacao in 1954.

In 1956 A. H. Baumhover established a Florida strain by crossing stocks collected in 1955 in Georgia and Florida. This strain was used, without adding new genetic material, for the eradication program in Florida in 1958-1959. A subcolony of that strain was maintained as an insurance colony at Kerrville during those years. In 1961 that subcolony was greatly expanded without the addition of new genes and it became the breeding colony for the eradication program that started in 1962.

In 1966 the Florida strain was completely replaced by a new strain of Mexican origin. At the end of 1968 that colony was supplemented by adding ten percent new flies also brought in from Mexico but how much of the new stock became genetically incorporated is doubtful. That strain was followed in 1971 by another strain from flies collected in Mexico. Screwworms collected in South Texas at the beginning of the 1972 outbreak became another replacement strain that year. Field tests in 1973 showed that another strain designated Tex-Mex was superior to the 1972 strain, so Tex-Mex became the breeding stock in 1974. It will probably be replaced in 1975.

(7) The seventh possibility - that the wild population may have changed has been proposed by insect geneticists writing in such prestigious journals as Science and Nature. It is possible

a discriminating strain of wild flies may have evolved. Such females might reject sterile males because of variation from wild-type in appearance, odor, or behavior.

There are size and color differences between media-reared and wound-reared flies. Researchers are now trying to rear laboratory flies that look more like wild ones. In addition to size and color differences, there may be other physiological differences that affect mating behavior in nature and hence might be the basis for lack of competitiveness of sterile flies. In recent tests APHIS and ARS entomologists could not demonstrate that sterile flies were less effective in northern Mexico where sterile flies have been released for the past 10 years, than in southern Mexico where there has been little opportunity for selection pressure to cause evolution of a sterile male resistant strain. However, the experiment was not conclusive.

Wild flies could evolve in other ways than developing an actual preference for wild males by wild females. One reason that the sterile male technique works is that flies don't mate until they are at least 2 days old and that males and females that emerge together get widely separated during the precopulatory period. This permits sterile males to intersperse. Now if some flies reached sexual maturity in half the time they would disperse only half as widely and hence would be twice as hard to outnumber. M. M. Crystal has checked many new collections

for time of mating and has not seen any evidence of early maturity.

Another trait, not so easy to check would be a change in dispersal behavior. If males and females did not develop strong dispersal patterns until after mating, this would facilitate brother-sister matings as much as would early maturity.

Screwworms may have lost some of their migratory behavior. In the past it was of survival advantage for flies to scatter since small larvae are obligatory parasites that cannot complete their growth after death of the host when too many flies oviposit on one animal. But to keep from being outnumbered by sterile males it would be an advantage for the fertile insects to stay in the same vicinity.

Now, after all this glib talk about mating behavior of wild flies, I'll make a confession. I'm just guessing because all we know about mating is what we've seen in cages. No one has seen screwworms mate in nature. I don't know whether aggregation sites are involved, whether flies mate on the ground, in the bushes, in the tree-tops or whether he grabs her on the wing. There's lots more I don't know about screwworms but I won't continue. Once I talked too long on this subject and I was squelched by a lepidopterist who said if he were that ignorant about his moths, he wouldn't think of working on the sterile male technique.

The one thing I am sure of is that there is a great research need for young entomologists to learn much more about screwworm ecology, behavior, physiology and population genetics. Eradication is not as easy as it used to seem. We need research to find out why.

Footnotes

1/ Founders' Memorial Lecture presented at the ESA Annual Meeting, Minneapolis, Minn., December 2, 1974.

2/ For reference to publications see:

Bushland, R. C. 1971 Historical development and recent innovations. Sterility Principle for Insect Control. International Atomic Energy Agency, Vienna, SM-138/47, pp 3-14.

Bushland, R. C., 1974. Screwworm eradication program. Science. 184:1010-1.

References

1. Fournier, J. J. J. Lecture presented at the IAEA Annual Meeting, Minneapolis, Minn., December 3, 1974.
2. For reference to publications see:
 - a. Bushland, R. C. 1971 Historical development and recent innovations. Biological Principles for Insect Control. International Atomic Energy Agency, Vienna, SM-138/47, pp. 3-14.
 - b. Bushland, R. C. 1974. Insecticide resistance program. Science 184:1010-11.

✓ EAT
✓ WFS
— JE
— NC

Reply to:
1514 Xanthisma
McAllen, Texas 78501
January 20, 1975

Mr. David Beckler
Assistant to the President
National Academy of Sciences
2101 Constitution Avenue
Washington, DC, 20418

Dear Mr. Beckler:

Thank you for your letter of January 13 asking that I answer three further points you outlined. I trust that the following will suffice:

- (a) Dimension and nature of the screw worm problem.
1. Screwworm larvae are obligatory paracites of warm blooded animals in the tropics and subtropics of the Western Hemisphere, spreading into adjacent temperate zones each summer.
 2. Screwworms, accidentally introduced through shipment of infested cattle, first appeared in the southeastern U.S. in 1933. This established a new, isolated population which caused millions of dollars annual loss in Florida and adjacent states.
 3. The U.S.D.A., in cooperation with state agencies, attempted to eradicate the new population using insecticides, repellants and animal husbandry practices during 1935-7.
- (b) State of the art at time Knippling proposed release of sterilized flies.
1. Ecological studies by U.S.D.A. indicated that screwworm populations averaged less than 100 flies per square mile of infested area.
 2. U.S.D.A. workers had developed laboratory culture techniques for rearing large numbers of flies at low costs.
 3. Knippling was the first person to propose releasing sterile insects to outnumber a wild population and compete for mates.
 4. Geneticists had induced dominant lethal mutations with radiation since 1927 but no one had suggested that genetics laboratory technique for practical control.
- (c) Way in which the screwworm problem had come to Knipplings attention.
1. The U.S.D.A., since 1913, has been the world's principal agency for the study of screwworm biology and control.

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JAN 21 1975

AREA OFFICE
WESLACO, TEXAS

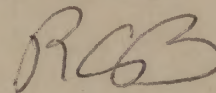
January 20, 1975
McAllen, Texas 78501
1514 Xanthus
Reply to:

Mr. David Beckler
National Academy of Sciences
Page 2
January 20, 1975

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2. Knipling was assigned by the U.S.D.A. to study the biology and ecology of screwworms.
 3. His observations on the newly established southeastern populations inspired him to propose the sterile male technique.

I hope that you received the copy of my manuscript, "Screwworm Research and Eradication" that I sent with my note of December 19. The items covered in this letter are discussed in that paper.

Sincerely,



R.C. Bushland
ARS Entomologist, Retired

RCB/tm

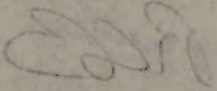
cc: E.F. Knipling
E.A. Taylor ✓

Mr. David Becker
National Academy of Sciences
Page 2
January 20, 1975

2. Knifing was assigned by the U.S.D.A. to study the biology and ecology of screwworms.
3. His observations on the newly established southeastern populations inspired him to propose the sterile male technique.

I hope that you received the copy of my manuscript, "Screwworm Research and Evaluation" that I sent with my note of December 19. The items covered in this letter are discussed in that paper.

Sincerely,



R.C. Bushland
ARS Entomologist, Retired

RCB/tm

cc: E.F. Knifing
E.A. Taylor

COPY

THEODORE CARROLL BYERLY
6-J RIDGE ROAD
GREENBELT, MARYLAND 20770

August 28, 1975

Dr. Dave Beckler
National Academy of Science
2101 Constitution Avenue
Washington, D.C. 20418

Dear Dave:

I have reviewed the Bushland draft case study on the screw worm program. It is first-hand, readable, frank - and optimistic. No one but Bushland could have described the history of the program in such intimate detail.

From the administrative standpoint it is a good illustration of the problems and time required to fund and implement an action program based on new technology. It illustrates equally well the expedients used to sustain program costs, initially and ultimately, at federal expense with interim inputs from States and interest groups.

Having committed itself to the program, USDA has extended its support, including a Mexican adjunct funded for fiscal 1975 at \$9,662,500 on the assumption that eradication by sterile fly dispersion in Mexico will maintain eradication in the U.S. A cost-benefit determination was made by APHIS last year. It indicated about a 2.5 favorable ratio for the program in the U.S., using a 10% discount rate. Such determinations are required increasingly in budget making and budget defense. The data base for benefits is, in my opinion, inadequate.

Bushland states (on page 34) that "screw worm control is now more difficult than at the beginning of the program and the reasons have not been determined." Despite intense, sustained effort at eradication, I am informed by a representative of APHIS that there were 7415 reported infestations with screw worm in the U.S. in fiscal 1975. Despite these difficulties Bushland concludes (page 36): "I am confident of continued success." Such confidence may have contributed to the success of the eradication programs in Curacao, Florida, and Puerto Rico. It is an important factor in funding and conducting action programs.

RECEIVED

SEP 15 1975

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WESLACO, TEXAS

W. Snow
Eal
copy to model snow
9/16/75
9/16/75

UNITED STATES DEPARTMENT OF AGRICULTURE
ANIMAL AND PLANT HEALTH INSPECTION SERVICE

In my opinion, the paper would be improved by deletion or modification of some statements which may be construed to be pejorative, e.g. those marked * on pages 13, 16, 18 and 19. There are a good many statements of opinion which are unsupported. While Bushland-Knipling opinions in this area are both informed and competent, they should appear clearly as opinions, not as conclusions based on objective evaluation of empirical information.

I have made interlinear and marginal comments and suggestions on the draft. You are free to transmit this letter and these comments to Bushland and Knipling and attribute them to me.

Sincerely,

Ted

T. P. Byerly

UNITED STATES DEPARTMENT OF AGRICULTURE
ANIMAL AND PLANT HEALTH INSPECTION SERVICE

VETERINARY SERVICES
SCREWORM ERADICATION PROGRAM
POST OFFICE BOX 969
MISSION, TEXAS 78572

Reply to: 1514 Xanthisma
McAllen, Texas 78501

September 12, 1975

Mr. David Beckler
Assistant to the President
National Academy of Sciences
2101 Constitution Ave.
Washington, D. C. 20418

Dear Mr. Beckler:

Enclosed is a revised copy of my screwworm manuscript. On almost every page I have made changes in pencil to incorporate the suggestions of Dr. Byerly and Dr. Hoffman. Through the cooperation of APHIS Screwworm Headquarters, Dr. Meadows' secretary retyped pages 22, 28 and 29 where extensive changes were necessary. I trust that it will be practical for one of your secretaries to retype the other pages of the manuscript with the penciled changes.

I deleted all the material Dr. Byerly found objectionable and included most of his suggestions. I could not expand the manuscript to answer some of Dr. Hoffman's questions but I believe that most of the information he requested is in footnotes or the literature cited. In that connection, I am enclosing two copies of my recent publication, "Screwworm Research and Eradication" (reference 26), which more fully covers the Southwestern program and current problems in control. Would you please send a copy of that paper to Dr. Hoffman. Also would you and Dr. Hoffman consider sending copies of that paper to the Russians as a more detailed explanation of the screwworm situation since 1972.

I was pleased to make the changes suggested by Dr. Byerly and Dr. Hoffman. I think that their editing has significantly improved the manuscript.

Sincerely,

R. C. Bushland
ARS Entomologist (Retired)

cc with Xerox of revised Ms to: Dr. Meadows
Dr. Knipling

Dr. Byerly
Mr. Taylor ✓

*Mr. Taylor:
Will you please make any
distribution needed within ARS.
I didn't bother you or Mr. Hart about
this typing because it was easier to
get the help of APHIS since I had to
visit Dr. Meadows for information anyway.
Bush*

Eradication and Suppression of the Screwworm Fly

by the Sterile Male Technique

I. Introduction

A. Responsibilities of the United States Department of Agriculture for screwworm research and eradication.

During the past century the United States Department of Agriculture
a major supporter
(USDA) has been ~~the leader of~~ agricultural research in the United States.

Cooperated
The USDA has ~~shared~~ with State Agricultural Experiment Stations in plan-
ning, funding and conducting research in all 50 states. *Much* ~~Most~~ of this ~~coop-~~
~~erative~~ research is done on the campuses of state agricultural colleges and
universities and at branch experiment stations in the state research systems.

The Agricultural Research Service (ARS) of the USDA conducts an
extensive program of scientific investigations with its own staff of
Civil Service
federal ~~employees, in the Career Civil Service.~~ The best known location
for this work is at Beltsville, Maryland where a variety of laboratories
are established and a National Program Staff is headquartered to coordinate
research on agricultural problems. Most ARS research is conducted at
field stations located in agricultural production areas where there are
practical problems to be solved. Laboratory locations may be temporary or
permanent, depending on research goals.

Entomological investigations have been conducted in the USDA ~~ever~~
for the past 100 years.
~~since national agricultural research was started about a century ago.~~

The opportunity to work with insects at varied field locations, to
investigate biology and control, out-of-doors and in the laboratory
with the resources of a national research establishment has attracted
entomologists to careers with the Agricultural Research Service.

~~Although~~ other agencies, especially universities and State Agricultural Experiment Stations are active in entomological research with emphasis on crop pests. ^{among} The USDA has been ~~the~~ world's leader^s in the field of livestock ^{research} insects and has conducted virtually all screwworm research.

Within the USDA, as currently organized, research on the basic biology and on techniques for control of insects is a function of the Agricultural Research Service (ARS) while a sister organization, the Animal and Plant Health Inspection Service (APHIS) is responsible for ^{conducting} ~~executing~~ national and regional programs on insect control. This report, therefore deals with ^{those} ~~two~~ organizations within USDA. ~~Pioneering research and field experiments are done by ARS and the eradication programs are managed by APHIS.~~

B. Dimension and nature of the screwworm problem in 1938.

Screwworms, Cochliomyia hominivorax (Coquerel) are parasitic maggots of a blow fly in the family Calliphoridae. The flies of most species in this family deposit their eggs on carcasses of mammals, birds and fish and the maggots grow in the decaying flesh. Screwworms are different--the flies oviposit only on living animals and the larvae must begin their growth in a wound on a living animal, although if the host should die, partly grown maggots can sometimes finish their growth in a carcass.

The insect was given its Latin name hominivorax, which means "man-eater" because the first specimens known to science were collected from cases of human myiasis. Some human cases occurred in the Southern United States each summer during the years of screwworm abundance but the insect chiefly attacks livestock and wild animals and is of only minor medical importance.

Flies will oviposit on any wounded warm-blooded animal but major wild hosts are the larger animals ranging in size from rabbits to deer. ^{Small} ~~Small~~ wild animals such as rodents are killed by the feeding larvae before the maggots can finish growing. The most important hosts are farm animals.

The most common site of infestation is the navel of new-born animals. During summer outbreaks, almost every calf, kid goat, lamb or pig ~~is~~ *may* be subject to infestation from time of birth until the navel heals. New-born animals must be protected by appropriate insecticides or they *are likely to* become infested and die. Other common sites that attract screwworm flies to oviposit and produce infestations are: man-made wounds such as brands, castration and dehorning wounds, ~~also~~ accidental cuts and scratches, various sores and areas irritated by tick and insect bites. The cost of appropriate animal husbandry, such as inspecting livestock, treating infestations and applying protective chemicals was a greater expense than the actual loss from death or injury. It was estimated in the 1950's that average annual screwworm loss exceeded 20 million dollars in the Southeastern U.S. and was about 100 million in the Southwest. Dollars costs were smaller in the depression years of the 1930's when prices were lower but screwworms have caused major losses ever since there was a livestock industry in the Southwest.

Screwworms are native to the tropics and subtropics of the Americas extending from Argentina to the Southwestern United States. The insects cannot withstand winter weather being limited in cold winters to areas warm enough for citrus trees to grow.

Screwworms survived the winter in the southernmost parts of the United States bordering Mexico. In the summertime they ~~spread~~ *migrated* northward to about the latitude of Sacramento, California and Kansas City, Missouri but they did not spread very far east of the Mississippi River. With the onset of winter the insects were killed back each year nearly to Mexico.

In 1933 screwworms first appeared in Georgia, apparently having been introduced through shipment of infested cattle from the Southwest. The flies spread into subtropical Florida where they were able to survive

the winter and established a new Southeastern population. Each summer screwworms spread from peninsular Florida over Georgia, Alabama and the Carolinas. Some years flies from the Southeast moved as far west as eastern Mississippi and flies from the Southwest spread almost that far to the east, ~~But~~ the two populations seldom if ever merged, and no flies overwintered in the area between ^{Southern} Texas and the Southeast.

In addition to dispersal by flight through normal summer migration, screwworms were also spread through shipment of infested livestock. Infestations have been recorded as far north as New Jersey in the East and South Dakota in the Midwest where livestock suffered severe losses until fall frost killed the flies.

The USDA had done screwworm research since 1913 when a livestock insects laboratory was established at Dallas, Texas. Subsequently screwworm laboratories were established at Uvalde and Menard, Texas in the ranch country where screwworms were most damaging.

The screwworm fly looks very much like another species of blowfly, Cochliomyia macellaria Fabricius which occasionally infests living animals but breeds chiefly in carrion. Entomologists confused the two species until 1933 when E. C. Cushing (1) of the USDA proved that macellaria and hominivorax were distinct species. C. macellaria is very abundant since it breeds in carcasses but hominivorox is relatively rare since the larvae are obligatory parasites (2).

This discovery occurred in the same year that screwworms became established in the Southeast. There was double motivation for increased research. First, was the hope that with the new knowledge about the parasitic habit of the screwworm, ways might be discovered to eliminate this parasite. Second, the establishment of a new population in the Southeast necessitated ecological studies in that new environment.

There is always a time lag between scientific recognition of a new research need and congressional appropriation of funds for that purpose. In this instance it was a relatively short time--only two years. The process was speeded because the expanding population of screwworms in the Southeast created an economic emergency for the livestock industry in that area. Also there was the hope that, if this newly established population could be attacked quickly, it might be eradicated using the new-found knowledge about the screwworm's obligatory parasitism.

In July, 1935 funds became available to expand screwworm research in Texas and to establish a new screwworm research laboratory at Valdosta, Georgia.

Also at this time, the USDA in cooperation with the Southeastern agricultural agencies attempted to eliminate the new screwworm population ^{by conventional means}. Chemicals were provided to treat wounds in livestock and an intensive educational campaign was conducted to instruct farmers in the prevention and treatment of infestations.

The efforts were only partly successful. Screwworm populations were greatly reduced but enough larvae survived in wildlife and in ^{untreated} ~~neglected~~ livestock to perpetuate the infestation. The eradication attempt was abandoned after two years. The research laboratory at Valdosta, Georgia was also closed in 1937.

To conserve limited funds, field research was confined to the laboratories at Uvalde and Menard, Texas. The Uvalde laboratory specialized in ecological studies and the Menard laboratory sought improved methods of chemical control. No state or private agency in the United States was doing research on screwworms nor was there any research conducted in Latin America. If screwworm control was to be improved, advances seemed dependent on a few workers in the USDA.

C. State of the art at time Knipling proposed release of sterilized flies.

Ecological studies conducted by the USDA (3) indicated that even during favorable weather screwworm populations seldom exceeded 100 flies per square mile of infested territory. Larvae could grow only in wounds of untreated living animals and since neglected infestations killed livestock most farm animals were treated.

Although in nature screwworms grow only in living animals, USDA workers (4) had developed laboratory techniques to rear larvae cheaply on a mixture of ground lean meat, blood, water and preservative under incubator conditions. About 1,000 larvae could be reared using 1 pound of meat. Flies fed and mated in cages and the females could be stimulated to oviposit on fresh lean meat. Hence insects could be reared in large numbers at low cost.

Insects were reared primarily to have abundant material for experiments on chemical control.

Geneticists had induced dominant lethal mutations (5) in Drosophila as early as 1927 by treating flies with X-rays but no one had suggested a sterility technique for insect control. As entomologists, we knew that geneticists irradiated fruit flies to produce mutations for basic studies in heredity.

D. Origin of new initiative, 1938-46.

Dr. Knipling was working in a USDA laboratory at Ames, Iowa studying the biology and control of cattle grubs and horse bots when the Southeastern screwworm problem arose. He was assigned in 1935 to do screwworm research at the new Valdosta, Georgia laboratory where he made observations on the screwworm population in Georgia and Florida. He was particularly impressed by the low population density of screwworm flies as compared to most insect pests with less restricted breeding habitats.

In 1937 Knipling was transferred to the Menard, Texas laboratory where his primary assignment was to do field research on the development of more effective wound treatments than the insecticides and repellants then available.

As a spare time activity he observed the behavior of flies held in cages. Melvin and Bushland (4) of that laboratory had developed the artificial diet for rearing larvae and were maintaining large fly colonies, chiefly for insecticide studies.

Knipling noted that flies in cages began mating when they were two days old. (The mating is rather obvious. A male pounces on a female and they remain quietly in copula for about a minute. The female then struggles to dislodge the male. If a female rejects a male they roll and tumble in the bottom of a cage while he clings and she struggles to escape.) After a culture of flies is 4 or 5 days old matings seldom occur although males continue to pursue females until most of the flies have died ~~of old age~~ after about two weeks.

Knipling ^{observed} ~~proposed~~ in conversations with his associates R. C. Bushland at Menard and A. W. Lindquist at Uvalde that the females seemed to mate only once although the males were promiscuous. He suggested in those informal discussions in 1938 that, if only some way could be found to sterilize males, it might be feasible to rear, sterilize and release enough males to overwhelm the relatively few flies that survived the winter in Florida. No experiments were made at this time. In 1939 Bushland was transferred to Florida for mosquito research and in 1940 Knipling was moved to a mosquito laboratory in Oregon and Lindquist to gnat research in California.

In 1942 Knipling, Lindquist and Bushland were reunited at Orlando, Florida where they worked on insecticides and repellants to control insects of medical importance to the military. There was no screwworm

research but the scientists occasionally resumed their discussions of screwworm biology and Knipling expanded his theory of the possible utility of sterile males to control the isolated Florida population.

E. Further preliminary development, 1946-51.

In 1946 Knipling was promoted to leadership of all the USDA work on insects affecting man and animals with headquarters in Washington. He consolidated research by closing the laboratories at Dallas, Menard and Uvalde and transferring the workers to make one major livestock insects laboratory at Kerrville, Texas. Bushland was moved to Kerrville to lead research on livestock insects, including screwworms.

The Kerrville laboratory had ^{an annual} budget of approximately \$200,000 to cover work on such diverse problems as cattle grubs, ticks, lice and biting flies as well as screwworms. The chlorinated hydrocarbon and organophosphorus insecticides were just becoming commercially available; so Kerrville had a project of screening thousands of new chemicals. Those that appeared insecticidally active or promising as repellents had to be put through a series of progressively more stringent tests to select a few of the most effective insecticides for safety testing. This involved evaluating toxicity hazards to livestock and making residue studies with meat and milk.

These tests with chemicals had highest priority because the USDA urgently needed the information to guide its recommendations for livestock insect control throughout the United States. Therefore, only a minor effort ^{was} ~~could be~~ made on the sterility approach to screwworm control.

As time permitted, technicians observed cultures of screwworm flies to accumulate more evidence on mating habits. No females were observed to mate twice, *thus supporting Knipling's hypothesis.*

Hundreds of chemicals were screened as screwworm larvicides and as toxicants and repellants for adult flies. The insects that survived the chemical screening tests were kept together for a week. Then the females were

stimulated to oviposit. Egg hatching was checked to see whether there were any sterility effects. All of the results were negative.

The first progress came after Lindquist (who had been transferred to Corvallis, Oregon in 1946) read a review paper by Muller (6) in 1950. In this report Muller mentioned that large doses of radiation applied to Drosophila males could cause so many dominant lethal mutations that, when they inseminated normal females, they could not produce viable offspring.

Lindquist called the paper to Knipling's attention who wrote to Muller outlining the screwworm problem and inquiring whether it would be possible to sterilize males by irradiation without destroying their ability to compete for mates in nature. Muller responded that he did not know what to expect but that experiments were worth trying. Knipling forwarded copies of the correspondence to Bushland at Kerrville with instructions to proceed with irradiation experiments.

The laboratory could not afford to pay for X-ray services at a local hospital so Bushland consulted with a friend who was a medical officer at Ft. Sam Houston in San Antonio. He arranged for test insects to be irradiated at no cost to the USDA using cancer therapy X-ray equipment at Brooke Army Hospital.

The X-ray experiments (7) ^{eded.} ~~were~~ quickly successful. As a review of the literature on other insects had led us to expect, irradiation of eggs, larvae and young pupae was lethal, not sterilizing, but adult flies and older pupae, (nearly adult in their development) withstood the effects of irradiation that caused sterility. If pupae are held at a constant temperature of $27 \pm 1^{\circ}\text{C}$. they complete their development and emerge as adults after 7 days. Pupae 5 or 6 days old withstand sterilizing doses of radiation about as well as adults, and being easier to handle they were selected for

further study. Male pupae were sterilized by a dose of 2500 rad and females by 5,000 rad. The sterilizing dose caused about a 10 percent reduction in adult longevity but the insects tolerated doses up to 20,000 rad. The sterile males competed for mates equally with normal males in cage tests. Sterile females seemed as attractive as normal females to males.

We expected from our reading that gamma-radiation would be cheaper and easier to apply than X-radiation, but free X-ray facilities were available from the Army at Ft. Sam Houston; so we did our first field tests with flies sterilized as 5-day-old pupae with 5,000 rad of X-rays at San Antonio and shipped by air freight to Orlando, Florida.

Facilities were already available at that laboratory for research on insects affecting man. Two entomologists and 4 technicians were transferred to Orlando from other livestock insect projects to serve as staff; since we could obtain no increase in funds. Field tests were made at Sanibel Island on the Gulf Coast, a few hours drive from Orlando.

Screwworms were about as abundant on Sanibel Island as they were on the mainland during the winter months. There were no livestock on Sanibel. Presumably the screwworms bred in raccoons, opossums and feral house cats and some immigrated from ranching areas of the mainland and nearby islands. To estimate the wild screwworm population normal screwworm flies grown at Kerrville on artificial medium containing P^{32} (8) were first released on Sanibel at the rate of 200 radioactive flies per square mile. The flies were sufficiently labelled that they could be detected when caught in liver-baited fly traps merely by using the probe of a portable survey meter. Radioactive released flies were easily distinguished from nonradioactive wild flies. The female released flies were sufficiently radioactive that their eggs, laid in masses of about 200, could be separated from eggs laid by wild flies that oviposited on artificially wounded goats held in pens on the island. The

experiments were further checked by rearing screwworms on living cattle injected with radioactive phosphorous to label flies and their eggs.

All the results suggested that 100 sterile males (plus an equal number of sterile females since it was inconvenient to separate the sexes before release) per square mile per week should greatly outnumber the wild flies on the island.

There was next a test release of radioactive sterile flies which we caught in fly traps in smaller numbers than were noted earlier for fertile radioactive flies. We then continued to release sterile flies reared on the standard, nonradioactive medium. The results were most encouraging. Egg masses collected from trap wounds before release of sterile flies were almost invariably fertile. Two weeks after beginning weekly releases of sterile flies, sterile egg masses predominated in the collections. We knew that these eggs were from wild females because ~~wild~~ females sterilized with 5,000 rad could not oviposit typical masses of 200 $\pm$ eggs and only rarely laid a few scattered eggs.

In warm weather there is a new generation of screwworms every 3 or 4 weeks. After continuing releases for 4 weeks most of the eggs collected from goats were sterile. After time for 3 generations, oviposition by wild flies almost ceased; then a fertile egg mass would appear. Sanibel was only 2 miles from the mainland so we assumed that such egg masses were laid by wild females immigrating from untreated areas.

While the field tests on Sanibel Island were continuing we attempted to obtain a Cobalt-60 source. Research funds were not available in the screwworm budget. We heard that the Atomic Energy Commission had ^{available} ~~ample~~ funds to finance research on peaceful uses of atomic energy. Dr. Knipling appealed to the AEC for a grant and was refused.

~~The best that~~ he was able to arrange ~~was~~ for us to take screwworm pupae from Kerrville to Oak Ridge National Laboratory for a test irradiation with a Cobalt-60 gamma source. The laboratory results with flies treated at Oak Ridge were similar to our findings with X-rays so I made a special trip to Oak Ridge to obtain the loan of a gamma-ray source.

Dr. A. Hollaender of the Biology Division after consulting with his staff agreed to loan us a primitive, nearly obsolete, 11-curie Cobalt-60 source that was being replaced by more modern equipment. But first I had to attend the month-long Radioisotopes Techniques Training Course and spend an additional week for specialized training in the Biology Division. This was necessary for me to obtain an individual license to work with Cobalt-60 because, in 1952, the USDA did not yet have a general license and a radiological safety officer to assure safe use of radioisotopes.

In March, as soon as my isotopes training was finished, Oak Ridge shipped the source to Kerrville and we did a series of comparisons of X-ray and gamma-ray treatments. The results (9) with both kinds of radiation were similar so we were able to switch to gamma-irradiation.

In the summer of 1952 we started rearing screwworms at Orlando and moved the 11-curie source there. This greatly simplified the logistics of doing field tests with sterilized flies. Experiments were continued on Sanibel Island and some releases were made on the mainland.

The little 11-curie source had such a small capacity that we could sterilize only a few thousand flies per week and we needed something larger for significant field tests. We made an arrangement with the Biology Division of Oak Ridge whereby we paid all ⁰²⁵⁰⁰ ~~we could afford~~ ~~(\$2500)~~ and the Biology Division assumed ^{an equal} ~~the rest of the~~ expense to design, construct, calibrate and install at Orlando a gamma source specially made for

sterilizing insects (9). This source was delivered in 1953 and finally gave us the capacity to conduct a fairly large field test.

A request was made to budget authorities in the ARS for funds to undertake field research. An increase of \$25,000 was granted with the understanding that if the first field test showed real promise for the sterile male technique, ~~the budget would be doubled to \$50,000~~ ^{Could be requested} for the next year; and if those results should justify expanded efforts, the sterile screwworm budget would ~~become~~ ^{be proposed at} \$100,000 per annum.

All the other livestock insect projects at Kerrville, still budgeted at the 1947 level of \$200,000 per year, were suffering from "normal" increases in salaries and operating expenses, so there was some relief with this special screwworm appropriation but the project did not get the anticipated increases in subsequent years in spite of continuing encouraging results on this new principle of pest suppression. Fiscal demands of other programs in the ARS kept authorities from increasing the screwworm allotment beyond the initial \$25,000.

II Eradication of screwworms from Curacao.

The opportunity to conduct an eradication experiment on a completely isolated population came in 1954. Dutch officials in the Veterinary Service of the Government of the Netherlands Antilles requested advice from the USDA regarding screwworm control on Curacao. A. H. Baumhover of our staff visited Curacao and found an ideal situation. The 170 square mile island was small enough for our limited resources. ~~Neglected~~ sheep and goats, ~~raised only for meat~~, roamed almost unattended, serving as hosts for screwworms. Chemical treatments were not used on these animals which remained ~~neglected~~ ^{untreated} during the test of sterile flies.

The experiment has been described in detail (10) so only a summary is necessary here. Sterilized pupae were packaged in small paper bags at Orlando and shipped by air freight to Curacao where the flies emerged. The paper sacks, each containing 100 flies, were opened and scattered from a small airplane flying twice weekly over the island in 1-mile swaths.

The initial release rate of 200 flies per square mile per week (which seemed so promising on Sanibel) was inadequate on Curacao. Sterility of egg masses collected from wounded goats averaged only 15 percent and this was not enough to depress the population density. The egg mass data showed that there screwworms were much more abundant than in our earlier work.

The release rate was then increased to 800 flies (400 males plus 400 females) per square mile per week. This rate caused about 70 percent sterility which depressed the population as measured by egg mass collections. An increasing ratio of sterile to wild flies resulted as reflected by a greater egg sterility. Eradication was apparently accomplished within 4 months but releases were continued an additional 2 months for insurance.

The apparent elimination of the screwworm population fulfilled the expectations predicted by mathematical models which Knipling had developed but not published. Finally we had proof that an isolated population of screwworms could be eradicated by the sterile male technique. Only then did Knipling publish his first paper (11) describing theories he had first proposed in 1938 and developed over the years in discussions with his friends. At the same time Lindquist (12) published his concept of the relatively small population density of screwworms to be encountered in a future eradication effort.

III Research to answer practical eradication problems, 1955-1957.

A. Magnitude of the Florida eradication problem.

Our screwworm surveys had shown that we could anticipate screwworms to survive the winter over about 50,000 square miles of the Florida

We assumed that

peninsula. [^] This area would require weekly releases of sterile flies to eradicate screwworms in the overwintering area. Since we had employed 800 flies per square mile for the success on Curacao, 800/sq.mi./week became the quota for Florida. For 50,000 square miles the estimated need was therefore 40,000,000 sterile flies each week. To provide for unavoidable mortality in the rearing, sterilization and distribution, and to maintain a breeding colony of fertile flies another 10,000,000 million flies were needed each week.

The maximum numbers reared for Curacao were 170,000 per week and that production taxed the capacity of our research facilities. In order to make realistic estimates of requirements for rearing 50,000,000 million flies and sterilizing and distributing 40,000,000 each week it was necessary to work on a $1/25$ th scale to develop mechanized equipment, labor-saving procedures and mass production techniques. This pilot effort has been described in a review paper (13) which may be consulted for more detail.

A military surplus, prefabricated steel building, large enough to rear 2,000,000 larvae per week was erected in a rural area where there were no people in the vicinity to suffer from air polluted by the stench of larva rearing. The odor from maggot-infested and only partly preserved rearing medium is unpleasant to all and nauseating to some.

All rearing through the Curacao experiment was done under incubator conditions in rooms or in ventilated cabinets heated to about 37°C. Neither arrangement was satisfactory for mass rearing. A great improvement was made when the staff developed a technique for growing the larvae in shallow, electrically heated vats in a well-ventilated room with fresh air to make working conditions ~~more~~ tolerable (14).

Mechanized procedures were devised by engineer C. N. Husman working with entomologists for all phases of insect rearing, separating pupae from larvae into precise age groups, irradiating pupae, packaging them in release boxes, loading airplanes and dispersing sterile flies.

The USDA ~~had finally~~ established a Radiological Safety Committee and the Safety Officer, M. E. Jefferson (15) working in cooperation with engineers at Brookhaven National Laboratory designed and built a Cobalt-60 gamma source with a capacity of sterilizing 20,000,000 pupae per week.

Our entomologists tested substitutes for horsemeat or lean beef which were the most expensive components of the larval diet. They found that less expensive whale meat (which was then commercially available to the pet food industry) was an adequate substitute.

All the prior field work had been with a laboratory strain of screwworms developed in Texas and later moved to Orlando. Since the Southeastern population of wild flies had been isolated from Texas flies since 1933 (about 200 generations) it seemed that sterile flies of Southeastern origin might perform better in field competition. So a special Florida strain was developed by collecting egg masses from naturally infested cattle in Florida and Georgia. Larvae hatching from these eggs were reared in the laboratory and the adults from each collection were caged separately. After several generations for the insects to become laboratory adapted, the most vigorous cultures were cross mated and combined into one Florida strain (16).

Ecological studies were continued in the field with trapping studies on wild flies and released sterile flies in central, northern and southern Florida. The results supported observations made on

Sanibel Island indicating that the released, sterile flies could disperse and survive in various areas inhabited by the wild population.

Observations on winter activity of screwworms were continued. Flies were active, causing natural cases during the coldest months of January and February on ranches as far north as Gainesville so that latitude was marked as the probable limit of overwintering with average winter temperatures. Records of screwworm cases from earlier years were reviewed to note winter activity in southern Georgia in the mildest winters, ^{and} A flexible plan was developed to cope with varying winter conditions.

Meanwhile, at the Kerrville laboratory, research had been continued on insecticidal control of screwworms with great success. A spray treatment was developed using the insecticide, coumaphos (17). This was a real improvement over previously used treatments which had to be applied by hand to each wound. The spray treatment made it much less expensive for ranchers to treat livestock. Penned cattle could be treated rapidly with a power sprayer. If cattle were generally wet with spray, screwworms were killed even in inconspicuous wounds, ^{unnoticed} ~~not noted~~ by the spray operator. Further, ^{more,} the spray treatment had a residual effect. Insecticide remaining on the hair killed larvae as they hatched from eggs laid as long as a week or more after spraying. This residual effect protected cattle in infested areas and was invaluable to the effectiveness of treatments made at quarantine stations on cattle possibly infested with eggs and being transported into screwworm-free areas.

By the summer of 1957 we thought we had enough scientific knowledge to support an eradication program. However, a large scale field trial was necessary before embarking on a full scale eradication effort.

Our research organization, then called the Entomology Research Division, was not the one to conduct an eradication program. At that time two agencies of the USDA could be responsible. The Plant Pest Control Division was largely an entomological organization but, as its name indicated, it had not been involved in control of insects affecting livestock. The Animal Disease Eradication Division, a veterinary organization, had a remarkable record in the control of ^{ticks and mites affecting} ~~diseases of~~ livestock but it had not been engaged in insect control.

~~Neither the Directors of those two Divisions, nor higher administrators in the USDA shared our enthusiasm for screwworm eradication. Thus, the~~ field trial was necessary for two reasons. First, we had to satisfy ourselves that our mass rearing, sterilization and distribution techniques would work on a pilot scale, large enough to develop a realistic eradication budget. Second, we had to convince USDA administrators that there was a high probability of success if an eradication effort should be made.

Another ^{policy} ~~requirement~~ for insect control programs in the United States is that the states involved share equally with the federal government in ^{except for exotic insect pests.} the costs for each state. Since the major cost was to be in Florida where screwworms overwintered, the program could not be undertaken without matching funds to be appropriated by the Florida legislature.

The State Veterinarian of Florida, Clarence Campbell, had followed our research since Curacao and was optimistic. He assisted us by providing livestock inspectors and some equipment from the Florida Livestock Board so that we could conduct the critical field test to which the Plant Pest Control Division and the Animal Disease Eradication Division assigned observers.

In the summer of 1957 we conducted our final field test using a 2,000 square mile area on the east coast of Florida near Orlando. In May, when fly releases began the region was suffering the worst screwworm outbreak we had ever seen in Florida. Every ^{new born} range calf, ~~born~~ if left untreated, became infested with screwworms. ~~The case incidence in susceptible animals was 100 percent.~~ Although we had previously planned on releasing 800 flies per square mile as used on Curacao, we increased the rate to the limit of our facilities which was 2,000,000 sterile flies per week or 1,000 per square mile (17).

Fly releases were made from May to August for 10 consecutive weeks. In the final weeks sterility of egg masses collected in the middle of the test area reached 70 percent (18). Since 70 percent sterility had caused a population decline on Curacao, we considered the demonstration a success. We did not attempt to achieve eradication since the test area was not isolated.

IV Southeastern Screwworm Eradication Program, 1957-1960.

After the pilot demonstration, the Animal Disease Eradication Division was designated by the USDA as the agency to be responsible for any eradication program. However, the Secretary of Agriculture ^{did} ~~was not sufficiently impressed~~ ~~to~~ request a Congressional appropriation so prospects were gloomy.

The situation was saved by the State of Florida. That legislature appropriated 3 million dollars to have funds to match any forthcoming Congressional appropriation. Florida senators and representatives then sponsored an appropriation for a federal program. With assurance of cooperation from the affected states, the Southeastern Eradication Program was approved in the fall of 1957.

The members of the Florida research team were transferred to the Animal Disease Eradication Division so that the program would have a nucleus of experienced entomologists and technicians. The Entomology Research Division continued in an advisory capacity but the program was managed by veterinarians of the Animal Disease Eradication Division cooperating with veterinary officials of the southeastern states.

The Entomology Research Division's laboratory at Kerrville, Texas maintained a colony of the Florida strain of screwworms as a potential replacement stock in the event of a disaster to the breeding colony in Florida. The Kerrville laboratory also continued research on insecticidal control of screwworms but screwworms no longer had first call on the limited research budget as the eradication program also had ~~an adequately~~ ^a ~~funded~~ Methods Development section to do practical research on current problems.

About December 1, 1957 the facilities for screwworm research at Orlando were turned over to the Eradication Program to be used for Methods Development projects and for training new employees in the techniques of rearing, sterilizing and distributing screwworm flies.

USDA procurement procedures are slow, involving elaborate specifications and competitive bidding procedures so it was more expeditious for the state of Florida to contract for the screwworm production facility. On a former U.S. Air Force base at Sebring, Fla., a hangar was fly-proofed and converted to an insectary with a capacity of more than 50 million sterile flies per week. The Sebring screwworm plant was to be ready July 1, 1958.

In December, 1957 and in early January, 1958 unusually cold weather occurred in Florida. The severe winter killed screwworms from the northern half of the peninsula reducing the size of the overwintering area to about half that in average years.

To take advantage of this situation a crash program was begun utilizing the Orlando pilot plant. Before the end of January sterile flies were being released at the rate of 1 million per week. Facilities were expanded while production continued. By July, when production started in the Sebring fly factory, 14 million flies were being dispersed each week from Orlando.

Warm weather came in February and screwworms began moving north by normal migration. Also a few cases were found in northern Florida and southern Georgia, apparently the result of shipping infested cattle from southern Florida. *Therefore,*

no A A quarantine line was established across Florida at the latitude of Ocala. All cattle shipped north of that line were unloaded for inspection and spraying at the quarantine line.

The rapid institution of a quarantine to prevent shipping of more screwworms, spraying of cattle in the localized areas of infestation north of the quarantine line, and special releases of sterile flies in those areas kept screwworms from becoming established north of Ocala.

The production of screwworms in the pilot plant was not sufficient to treat the entire overwintering area in southern Florida; so flies were released ^{only} in the northern half of the state in a sort of barrier zone. It was hoped that by maintaining a population of 200 or more sterile flies per square mile in northern Florida that any flies emerging as a result of undetected cases in that zone would be overwhelmed in mating competition by sterile insects. The strategy seemed successful as screwworms did not make their usual spring migration to Georgia and Alabama.

When the Sebring plant opened in July, 1958 and soon reached full production of 50 million flies weekly, the entire overwintering area and the barrier zone

were flooded with sterile flies. The usual release rate was 1000 per square mile per week but as the program neared its end more flies were available for heavier treatment of a few areas in which wild flies persisted. Screwworms almost disappeared in 6 months and the last case was recorded in June 1959. Sterile fly releases were continued for another 6 months before the Sebring plant was closed to assure eradication as some breeding might have continued undetected in neglected livestock and wild animals. Screwworms were eradicated from the Southeast at a total cost of approximately 7 million dollars, about one-third of the previous annual cost to the livestock industry there.

The program was completed a year earlier than anticipated, with the assistance of cold weather which so reduced the area to be treated. But cold weather and an abundance of sterile flies were not the only reasons for success. The development of an effective spray for the quarantine line and outstanding effort and complete cooperation by livestock regulatory agencies in the southeastern states were important factors as was the enthusiastic assistance of livestock producers whose good animal husbandry reduced screwworm incidence and whose prompt case reporting kept program officials aware of the field situation.

Our original goal was attained with the eradication of screwworms from the Southeast. It was thought that, after eradication, screwworms could be kept out of the region by an effective quarantine. Thirteen inspections stations were set up near bridges where major highways crossed the Mississippi and Pearl Rivers between Memphis, Tennessee and the Gulf of Mexico. All cattle, whether shipped by rail or truck, from the area west of the quarantine line had to be unloaded, inspected and sprayed or dusted with coumaphos.

This quarantine line was not completely effective in protecting the Southeast. In 1960 screwworms appeared in Tennessee, apparently as a

result of importation of infested cattle from the upper Midwest, north of the northernmost inspection point. The Tennessee outbreak spread into

In 1911, the first year of the outbreak, the Tennessee outbreak was the most serious. The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country.

The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country. The outbreak was the most serious in the history of the country.

For all these reasons there were pressures from various sources. From livestock producers, and from shippers to get rid of the infected animals in the Southeast.

V Southeastern Screwworm Suppression Program.

A. Differences in population ecology between the Southeast and Northwest.

The original screwworm problem was not isolated but was widespread. It could be traced to a well established population in the Southeast. It could be traced to a well established population in the Southeast. It could be traced to a well established population in the Southeast.

The Southeastern population is not isolated but is the southern fringe of a population extending through Mexico and Central America to the Isthmus of Panama. It is a well established population in the Southeast. It is a well established population in the Southeast.

northern Alabama where cattle were sprayed and sterile flies, shipped from Kerrville were released. This suppressed the population which was eliminated with the onset of cold weather.

In 1961, two years after eradication, screwworms appeared near Pensacola, Florida, apparently as the result of an infestation from imported cattle, in spite of the inspection and spraying practiced at the quarantine line. Cattle in the Pensacola area were sprayed with insecticides and sterile flies from Texas were released to eliminate the incipient outbreak.

The quarantine line was expensive to maintain. To cause minimum interference with interstate commerce, the 13 stations had to be manned 24 hours per day, every day of the year at an annual cost of about \$800,000. Trucking interests objected to the delay caused by unloading cattle for inspection and treatment. Livestock owners did not like that additional stress on the health of their animals.

For all these reasons there were pressures from regulatory agencies, from livestock producers, and from shippers to get rid of the source of screwworms in the Southwest.

V Southwestern Screwworm Suppression Program.

A. Differences in population ecology between the Southeast and Southwest.

The original ~~proposal and all of the~~ research had been oriented to develop methods for eliminating the recently established Southeastern population. That population was truly isolated during the winter months. It could be treated as a unit and overflowed with sterile flies.

The Southwestern population is not isolated but is the northern fringe of a population extending through Mexico and Central America to the temperate zone of South America. ~~If~~ ^S Screwworms ~~should be~~ eliminated

from the Southwestern States ~~they~~ could be replaced by migrants from Mexico.

The population in the Southeast probably had limited genetic diversity having as founders only those flies that were accidentally introduced in 1933 with probably a few more similar importations in subsequent years. ~~It is likely that all the flies were descended from a stock that was native to South Texas.~~

The Southwestern population was genetically diverse since it occupied its "permanent" range. ~~As there has been little shipment of livestock between Eastern and Western Mexico and until recent years not much more between Texas and California there was not much opportunity for exchange of genetically different stocks through commerce.~~ The mountains and deserts of Mexico and the Southwestern States limit migration between the East and West so genetically different populations would be expected. Also many isolated valleys of Mexico might have genetically distinct flies.

Therefore, the Southwest, with diverse environments probably occupied by genetically different strains spread over a range too extensive to test as unit, seemed beyond our resources during the early 1950's.

B. Perception of feasibility by scientists.

Our thinking was changed by the success of the barrier zone used to keep screwworms from spreading north from Florida in the spring and early summer of 1958. Our hopes were further strengthened by the success in keeping flies from spreading in Alabama in 1960 and by the elimination of a local outbreak in Florida in 1961.

Field entomologists of the Uvalde, Texas laboratory had studied overwintering and migration of screwworms in Texas for 10 years beginning

in 1935. ^{also} ~~Also from that date~~ There had been less thorough annual surveys of screwworms in New Mexico, Arizona and California ^{since 1935.} ~~from~~ ^{Beginning in} 1946 ~~in~~ the Kerrville laboratory made brief surveys each spring and fall to estimate the approximate overwintering areas and the maximum limits of summer spread by fly migration and by shipment of infested livestock ^{in the Southwest.}

We knew that in average winters screwworms survived only in a 50,000 square mile area of South Texas and in much smaller areas of New Mexico, Arizona and California. We knew less about screwworms in Mexico but from the general geography and climate of Northern Mexico we expected limited overwintering except in the eastern coastal plain of Tamaulipas.

By 1959 Knipling, Lindquist and Bushland reached informal agreement that there was a good chance screwworms might be eliminated from the major overwintering area in Texas with no more sterile flies than had been budgeted for Florida - 50 million per week. Then it might be effective to spread the flies over a 100-mile-wide zone along the United States-Mexico border as a living barrier to flies invading from Mexico.

The earlier field studies on screwworms had shown (19) that populations spread northward from overwintering areas at a rate of about 35 miles per week. Since in warm weather screwworm flies usually died ~~of old~~ ^{age} within 3 weeks it seemed unlikely that a mated female would survive to fly through the ^{100-mile-wide} barrier zone. If she oviposited within the barrier zone on an untreated animal the few resulting adults should be overwhelmed in mating competition by sterile flies dispersed over the zone at 200 flies per square mile per week. That rate had been effective against an established population in our Sanibel Island field tests.

We recognized all this as a possibility worthy of serious consideration and subsequently Knipling ^{proposed} ~~sought~~ funds to conduct an appropriate experiment. However, the test area needed to evaluate the practicality of a barrier zone was so large that a budget request was discouraged by USDA administrators.

The State Veterinarian of Florida encouraged development of a Texas program because he feared that Florida might become reinfested from Texas or the Midwest.

In 1959 officers of the Texas and Southwestern Cattle Raisers Association, a grower organization, visited the Sebring, Florida plant to learn about the Southeastern program and inquire about the possibility of a similar program in the Southwest. They were encouraged by their review of the project and the possibility of modifying the plan for trial in Texas.

It is customary for farm and ranch organizations to invite USDA scientists to speak at their meetings on progress in agricultural research. The USDA welcomes this opportunity to inform the public and also to learn from the growers about agricultural research needs. Farmers and ranchers are always welcome at USDA field laboratories when they visit seeking technical information. USDA scientists have the academic freedom to discuss their research and to interpret the results but ^{policy} ~~decisions to undertake~~ ~~policies for~~ action programs are made by administrators in Washington.

This was the situation regarding the further application of our screwworm research. The U. S. Department of Agriculture initially did not endorse an extension of the program.

Whenever my opinion was sought by individuals or by representatives of the livestock industry I spoke freely of my enthusiasm for extending

screwworm control to the Southwest even though this did not represent an official recommendation by the USDA.

There was great interest and political pressure from the livestock industry for such a program even though there was considerable uncertainty of success. This stimulated a budget increase for screwworm research of \$200,000, almost doubling the Kerrville budget ^{and permitted} ~~This enabled~~ the hiring of six new senior scientists to do research in support of a future screwworm eradication and containment effort. In 1961 new screwworm research was started at Kerrville on screwworm physiology, genetics, radiation biology, attractants, nutrition and ecology.

Based on the cost of the Florida program, it was estimated that a similar effort in Texas would cost about \$5 million per year. A field trial of sufficient scope to test eradication in only part of the South Texas overwintering area and protection of this limited territory with a barrier zone would cost more than \$1 million each year and might not be conclusive.

Leaders of the Texas grower organizations decided that they could not support such an expensive field test that would have little immediate benefit to the livestock industry outside the test area. Further, they were suffering about \$100 million annual loss from screwworms and they did not want to continue such losses ^{by postponing an eradication effort pending a field trial.} ~~with a solution in sight.~~

^{a test eradication program}
They preferred to risk \$5 million annually on ~~an experiment~~ which if successful, could save \$100 million each year. Both stockmen and entomologists recognized that such an untried effort as attempting to eliminate screwworms from 50,000 square miles of South Texas and then trying to keep Mexican flies from reestablishing a Texas population with a barrier zone was a gamble. This gamble seemed worth taking from the standpoint of estimated chances of success in relation to costs and benefits.

The growers organized in 1960 a nonprofit corporation, the Southwest Animal Health Research Foundation, to share equally with the USDA in financing the large scale eradication test. If the experiment succeeded they were confident that matching funds would be appropriated by the legislatures of the states in which control operations would be continued.

The major grower organizations, led by the Texas and Southwestern Cattle Raisers Association and the Texas Sheep and Goat Raisers Association, conducted an educational (20) and fund raising campaign in every county of Texas. They set an informal quota requesting livestock owners to donate 50 cents for each cow and horse, and 10 cents for each sheep, goat and pig.

The livestock producers responded so generously that the Foundation collected about 4.5 million dollars to match federal expenditures pending support from State legislatures. In February, 1962, Congress authorized a Southwestern program.

The Department of Defense transferred to the USDA an abandoned air base near Mission, Texas, for the establishment of a new sterile screwworm production and distribution center. The Southwest Animal Health Research Foundation contracted for the remodeling of old buildings and the construction of such new facilities as were needed for a program headquarters and production facility with a capacity of 100 million sterile flies per week.

The ARS screwworm research people at Kerrville were transferred to Mission in the summer of 1962 to do research in support of the APHIS program but they remained in the ARS organization. They were assigned research space in buildings that had been transferred to APHIS by the Air Force.

The ARS staff had rearing facilities for small scale experiments and could utilize the APHIS facilities for other tests. Large scale experiments were cooperative ventures with the Methods Development Unit of APHIS.

The Southwestern program was started as a crash effort because unusually severe cold in January and February, 1962 did not permit overwintering in the San Antonio area where flies usually survived. The facilities at Kerrville were used to produce increasing numbers of sterile flies beginning in March and continuing until August when the Mission plant was in full production.

Sterile flies from Kerrville were released in South Texas to combat flies migrating from overwintering areas in the Rio Grande Valley and Mexico. Not enough flies were available to make an effective barrier zone and screwworm spread across Texas into Oklahoma and Louisiana. However, there was a 90 percent reduction in the number of infestations in 1962 compared with earlier years based on reports from ranchers. Much of this reduction was probably due to the effects of the severe winter but records of sterile egg masses laid by wild flies on wounded experimental animals showed effective competition from sterile flies released in South Texas.

Cooperating growers sent 49,484 samples of screwworms to the Mission headquarters in 1962 while the reporting system was being established. The number of cases recorded in 1962 cannot be directly compared with the numbers for following years because reporting was incomplete. LaChance et al (21) devised a "correction factor" based on the number of samples of maggots other than screwworms identified each year. They concluded that, if reporting had been as complete in 1962 as it was in 1963, 2.7 times as many screwworms would have been identified during the first year of the program. In 1963, with cooperative reporting in full effect there were 4,916 screwworm cases reported. In 1964 APHIS identified only 223 samples of screwworms from Texas and in 1965 there were 466.

The 1964 cases occurred at widely scattered locations, but mostly within 300 miles of known screwworm breeding areas in Mexico. We had previously thought that screwworm flies could not fly more than 100 miles so ARS did a flight test (22) with dye-marked sterile flies. Sterile flies were recaptured 180 miles from the release point. If less robust, artificially reared sterile flies, further weakened by radiation could fly 180 miles, there was little doubt that some wild flies could fly 300 miles.

Thorough ground surveys by state and federal livestock inspectors and veterinarians showed that the scattered cases in 1964 could be attributed to wild flies migrating from Mexico. The sterile fly barrier zone, which was originally established 50 miles on either side of the Rio Grande River, *in cooperation with Mexican officials* was sometimes extended as far as 300 miles into Mexico to suppress the population overwintering in locations that particularly menaced the United States.

In 1964 no screwworms were found in Texas or New Mexico during a time sufficient for 2 or 3 generations. Accordingly, the USDA officially declared screwworms eradicated from Texas and New Mexico, even though the area was known to be subject to reinvasion from Mexico. That declaration freed those states from the expense of paying half the cost of the barrier zone. *since* It is a federal responsibility to keep foreign pests out of the United States.

Congress appropriated additional funds in 1965 to maintain the barrier zone and to share with Arizona and California the cost of eliminating screwworms from those states. In 1966 the whole United States was declared free of screwworms on the basis previously cited and it became a federal responsibility to maintain the 1500-mile-long barrier zone from Texas to California. The veterinary services of the border states actively cooperate by continuing their own screwworm surveys. In addition, livestock growers remain alert and send maggots to APHIS for identification whenever they find cases of myiasis.

Flies that usually deposit eggs or larvae on dead animals sometimes infest wounds and can be mistaken for screwworms. ~~That is why APHIS maintains an~~ identification center at Mission. Cooperators send larvae collected from livestock or wild animals to ^{an} APHIS ~~for identification~~. Identification records are vital to management of field operations.

As there is no control program against the various maggots that only occasionally infest wounds, the records on those miscellaneous larvae are a good index of rancher interest in case finding. If livestock owners watch their animals carefully there should be only minor variation from year to year. However, livestock owners observe their animals more closely when screwworms are active. So while the number of screwworm cases indicates the density of wild flies, the number of non-screwworms shows how carefully ranchers are observing their animals.

The total numbers for the United States of screwworms and total numbers of other species of maggots recorded (23) at the Mission, Texas identification center for each year since 1966 are tabulated below:

Identifications of larvae sent to APHIS by Southwestern livestock producers.

<i>Calendar</i> Year	<u>Number of samples submitted</u>	
	<u>Screwworms</u>	<u>Other species</u>
1966	1,875	4,573
1967	872	3,846
1968	9,878	4,394
1969	219	3,101
1970	153	2,028
1971	473	2,584
1972	95,625	4,185
1973	15,016	3,986
1974	7,273	2,951
1975 (Jan. 1 thru Sept. 12)	7,727	2,335

Although screwworms were declared eradicated from the United States in 1966, there have been reinvasions from Mexico each year. The application of the term "eradicated" to an area where screwworms continue to be found has caused controversy, ~~among some entomologists.~~

As mentioned earlier, ~~the reason for using the term "eradicated" was primarily legal.~~ If the USDA had not declared screwworms eradicated, the four states bordering Mexico would still have to pay half the cost of maintaining a barrier zone that also protects many other states from migrating flies.

^{Some}
~~Most~~ years there have been no continuously breeding populations of screwworms within the United States. Flies invade from Mexico and oviposit on our livestock and wild animals. Sometimes that first generation infestation will be found by an alert rancher who will take a sample of larvae for the identification record and apply a larvicide to eliminate the infestation. At other times the larvae may grow unnoticed in neglected livestock or wildlife. The barrier zone exists for such situations.

^{assume}
We ~~hope~~ that the preponderance of sterile flies in the barrier zone will mate with the adults of the new generation as they emerge and that there will be little or no mating between wild males and females.

Occasionally infestations may persist in an area for a few generations but a combination of good animal husbandry and sterile flies eliminates an incipient outbreak. That was the situation in 1966 and 1967. In 1968 screwworms increased for a while but were apparently eliminated by the end of the year and 1969, 1970 and 1971 were relatively screwworm-free with no continuous breeding found anywhere in the United States.

^{do not object}
I ~~see no objection~~ to maintaining that from a technical standpoint screwworms were repeatedly eradicated from the United States, recognizing full well that the area is subject to reinvasion each year by long range migrants.

In 1972 screwworms got out of control in the Southwest, particularly in Texas where they migrated across the state spreading as far north as Kansas. Screwworms were also accidentally shipped from Texas to Florida but were quickly eliminated. Only two infested cattle were found in Florida. Those cases stimulated an intensive localized program of control by release of sterile flies, spraying of cattle and encouragement of preventive animal husbandry.

Although screwworms were widespread in 1972, damage was concentrated in the southern portion of Texas. Considering the livestock industry of the Southwest, the case incidence was only ^{a small percentage} ~~about 5 to 10~~ percent of that experienced in the years prior to the sterile fly program. ~~Even during 1972 the technique was more successful than most pest management programs.~~

In 1973 screwworms were under control in most of Texas and ^{However, in 1975 the situation in Texas is not as good as in 1974} in 1974 there was further improvement. As far as the livestock producers are concerned, the program is a huge success.

The most disturbing feature of the increased case incidence since 1972, is the failure to prevent a succession of generations in the overwintering area of the lower Rio Grande Valley. In several thousand square miles of the southernmost part of Texas, some screwworm cases have occurred throughout each year. I can only conclude that the population which increased to substantial numbers in 1972 has not since been eliminated.

VI Problems, in Screwworm Eradication.

A. Southwestern program.

There has been much speculation (24) regarding the causes of the 1972 outbreak and our inability to again reduce the case incidence to numbers that would result from occasional reinvasions from Mexico.

Failures have been attributed to one or more of the following reasons:

- (1) Mild winters and rainy summers that favored above normal winter survival and summer increase of flies.
- (2) Changed ranch practices that have greatly increased the number of neglected livestock and increased ^{the probability of} ~~their susceptibility to infestation~~ ~~with the resultant~~ production of more wild flies.
- (3) Because of conditions (1) and (2) there have been insufficient numbers of sterile flies to achieve the overflooding ratios attained in prior years. There have also been budget limitations (25).
- (4) Less vigorous and competitive sterile flies associated with changed rearing practices, particularly because of substitutions for meat in the larval diet.
- (5) Poorer dispersal of sterile flies as a result of increasing the distance between flight lanes of aircraft distributing flies.
- (6) Genetic deterioration of laboratory breeding stocks.
- (7) Genetic changes in the behavior of the wild population because of selective pressure in the barrier zone.

I have discussed all seven points in a recent review (26). I believe that much more research, particularly in the areas of physiology, ecology and population genetics (27) is needed. While the program continues to be highly successful, screwworm control is now more difficult than at the beginning of the program and the reasons have not been determined.

B. Eradication of Screwworms from Puerto Rico.

In 1971 the USDA, in response to a request from the Commonwealth of Puerto Rico, began an eradication effort on the main island and some adjacent smaller islands including Vieques, Culebra and some of the American and British Virgin Islands. The total area was only 3800 square miles.

Sterile pupae from the Mission, Texas plant were flown by the U.S. Air Force to Puerto Rico where the flies emerged and were distributed by Air Force pilots. Ground facilities were supplied by the Air Force and by the U.S. Navy.

The eradication effort required 4 years for completion, much longer than was anticipated at the beginning of the program. In 1971 it seemed that eradication might require only adequate numbers of sterile flies. However, progress was slow on Vieques and on the main island of Puerto Rico. Success was not attained until veterinary services of the Commonwealth of Puerto Rico made an intensive effort in educating livestock owners in animal husbandry practices to limit numbers of susceptible animals and to find and treat those infested. This was necessary to limit the number of wild flies to be overwhelmed with available sterile flies. Other problems to be solved involved the logistics of shipping sterile insects so far, training new technicians in fly handling and release procedures.

The experience which emphasizes the need for both good animal husbandry practices and adequate numbers of sterile flies should be helpful in future eradication efforts in tropical environments.

C. The Mexico-United States Eradication Program.

In 1973 the two governments formally established a Mexico-United States Commission for the Eradication of Screwworms with headquarters in Mexico, D.F. The Commission has a sterile screwworm plant now being constructed near Tuxtla Gutierrez, Chiapas, Mexico. When this plant is ready in 1976, it will have a capacity of 300 million sterile flies per week.

The Departments of Agriculture of the two countries are jointly furnishing veterinarians and entomologists for technical management

of an eradication program intended to eliminate screwworms from North America as far south as the Isthmus of Tehuantepec and to maintain a barrier to reestablishment in that area. This new barrier zone will be only about one-tenth the ^{length}~~width~~ of the current 1500 mile barrier along the U.S.-Mexico border. As soon as the new plant can reach full production, 500 million flies will be released each week, 200 million from Texas and 300 million reared in Chiapas. When the new program is largely accomplished, the APHIS plant in the U. S. will be closed and placed in stand-by condition to be ready for any future need. The Commission plant in Mexico will produce as many sterile flies as are needed to supply a buffer zone across the Isthmus of Tehuantepec.

This forthcoming eradication program in Mexico requires an expanded research and development effort. It is anticipated that there will be many new problems encountered in the varied environments of Mexico.

The quick elimination of wild flies -- as experienced on Curacao, in the Southeast and in the early years of the Southwestern program -- has encouraged expectations of equally rapid success in Mexico. The new program will be more difficult and will require much more research support.

Considering the problems, scientific, administrative, and political, that have been surmounted to bring screwworm eradication and containment to its present state, - I am confident of continued success.

Footnotes

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